July 2009

Sweep Rigger

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Project Number: 2ME GT SE08

Design of Sweep Rigger for Ergometers

A Major Qualifying Project Report

Submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for the

Degree of Bachelor of Science

in Mechanical Engineering

by

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Date: May 13, 2009

Approved:

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keywords

1. Ergometer
2. Rigging
3. Crew
4. Rowing

Abstract

The goal of this project was to design, build, and test an accessory to the existing Concept 2 Indoor Rower that would allow a rower to move in a sweep rowing motion off the water. Currently, there is one commercially available sweep ergometer which costs over four times more than the most widely used ergometer, the Concept 2. A 3D solid model of the design was made with SolidWorks which includes a mechanism that would allow the ergometer chain to stay centered while the handle moves in an arc. Two prototypes were built, the first as a structural test for comparative measurements of body variations and the second as a fully working product. The second was tested by rowers from Worcester Polytechnic Institute.

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1. Introduction

1. 1 Objective

The objective of this project is to design, build, and test an ergometer attachment that will incorporate the sweep motion of "on the water" rowing, off the water. This design can be used on any Concept 2 ergometer because of structural design similarities. Furthermore, the sweep rowing attachment can be marketed to the entire rowing community for use in the off season and during inclement weather.

Our design will be simple, adjustable, and durable. An individual will be able to attach our product easily with minimal tools. Our design will pose no threat of damage to the ergometer and can be removed to return the ergometer to its original condition.

1.2 Rationale

With roughly four hundred collegiate crews in the US and Canada alone, our revolutionary design is a drastic advance in off the water training. The few sweep rowing ergometers available are expensive and inadequate for the hundreds of teams that already own different models of the Concept 2 ergometer.

Good rowing maximizes strength and form which our design incorporates to achieve a full rowing workout. Merging off the water and on the water techniques, our design utilizes what rowers know. Our design expands the existing market to revolutionize the ergometer experience.

2. Background

2.1 Rowing

There are specific NCAA rules that prohibit coaches from training rowers out of the competitive season. In most cases rowers can only access rowing shells and water time through their coaches, leaving seven out of twelve months when competitive crews from age twelve to twenty-four are forced onto indoor rowing machines. Indoor rowing machines, ergometers, allow a rower to maintain strength but not technique. Balance in a racing shell, which can only be attained through proper rowing technique is often times more important to coaches than mere strength. Thus, in the two and a half months a rower has per season, it takes approximately two weeks of practice for a rower to regain proper technique lost during the off season. With two seasons a year, one of the five months which rowers are able to spend on the water is lost, to again attain proper technique. Figure 2.11 shows a side view of the proper rowing technique which is utilized on and off the water [7].

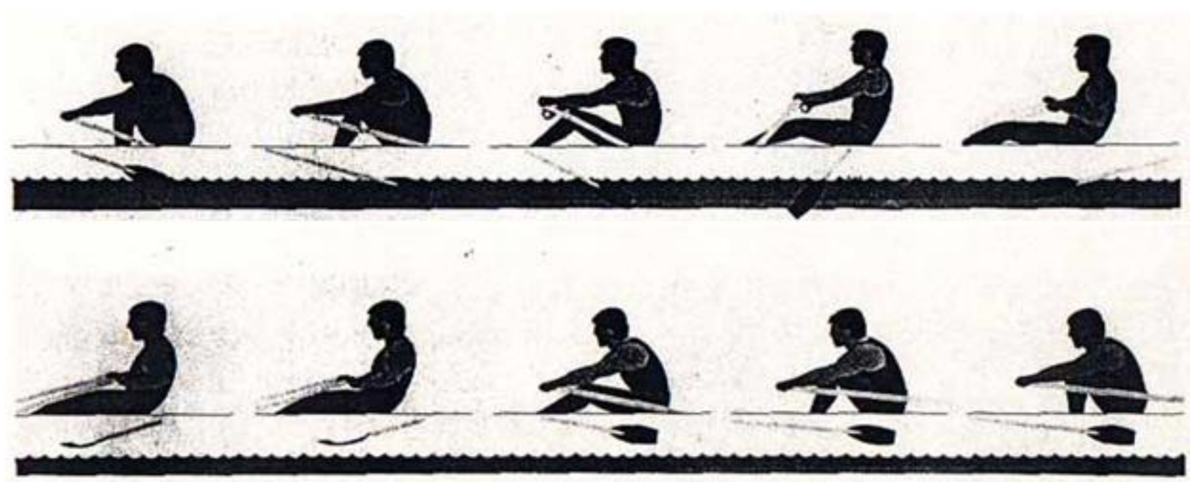


Fig 2.11 Proper Rowing Technique

On an ergometer a rower's body must stay centered to effectively use the rowing machine. The difference between staying centered and the sweep motion can be seen in figure 2.12. There are multiple muscle groups along the side, shoulders, and arms that are affected by the difference in motion. During the sweep motion, a rower must always put pressure on the pivot, often called the lean, doing so stabilizes the shell when the rowers are synchronized [7]. As the ergometer does not allow for lean, coaches have been known to forbid their rowers from erging in season as it trains bad habits.

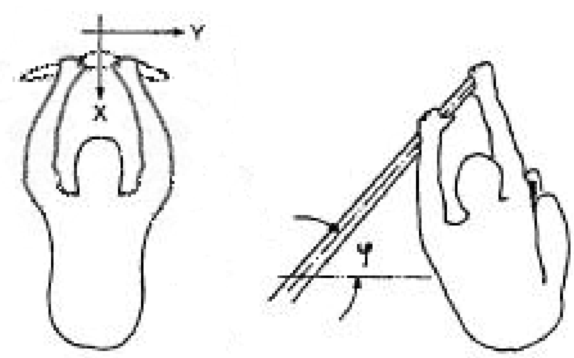


Fig 2.12 Rowing on Erg vs. Rowing on Water

2.2. State-of-the –Art

Figure 2.21 exhibits the most widely used Concept 2 erg, model D [5]. Although Concept 2 is the leading manufacturer of indoor rowing machines, there are other commercially available ergometers, many of which incorporate the sweep or sculling motion of on the water rowing. Both US Patent 5,658,225 [4] of figure 2.22 and US Patent 4,695,050 [9] of figure 2.23 incorporate a form of the sculling motion but are not comparable to on the water rowing. Figure 2.24 shows a rowing machine, from US Patent 4,743,011 [2], that incorporates the correct sculling motion but it is still unable to be used for sweep rowing as the rower must use two oars instead of the one properly used in sweep rowing.

Fig 2.21 Concept 2 Ergometer, Model D

Fig 2.22 US Patent 5,658,225

Fig 2.23 US Patent 4,695,050

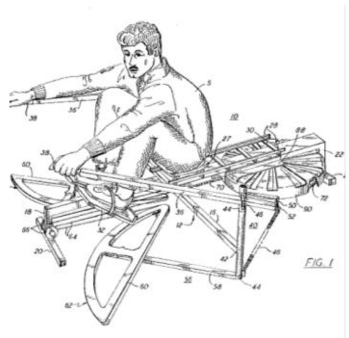


Fig 2.24 US Patent 4,743,011

Moreover, both these patents lack a monitor for feedback on distance traveled, power of the stroke, strokes per minute, and overall time, which all rowers need to improve on their speed and strength. Furthermore, US Patent 4, 867,447 finally incorporates a monitor in the Stamina model [6] but this model still lacks the versatility of the true sweep rowing motion. The only existing ergometer that comes close to our design is the sculling ergometer of US patent 5,441,469 implemented in figure 2.25 which utilizes the sculling motion with two oars, however, rowing with a single oar is impossible on this rowing machine [1]. The only rowing machine currently in existence that allows a rower to sweep row indoors originates from Australia. The Oartec, pictured in figure 2.26, can be used as a sweep rower [8], however; it also costs over four times the original price of the widely used Concept 2 ergometer [3].

Fig 2.25 US Patent 5,441,469

Fig 2.26 Oartec Ergometer

3. Approach

Axiomatic design was used to develop our design because of linear progression. Marketability is the number one consideration in our design, closely followed by ease of use. Our design is lighter and simpler than the commercially available sweep ergometer designed by Oartec. Our design incorporates the feel of on the water rowing that rowers look for in training gear. Experienced and inexperienced rowers alike can benefit from our design and can be sold as an addition to any model of the Concept 2 ergometer. Figure 3.01 is a simple diagram of the Concept 2 model D ergometer and its components which will help to better understand the design concepts [11]. Our design, figure 3.02, is important to the rowing community because it finally addresses a missing component for year round training.

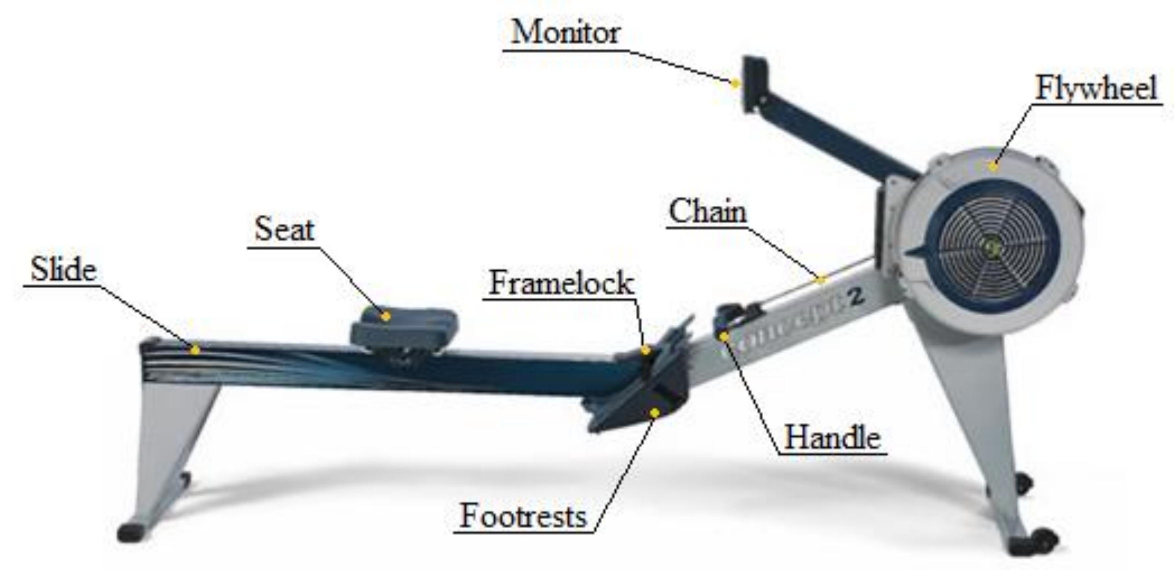


Fig 3.01 Ergometer Parts

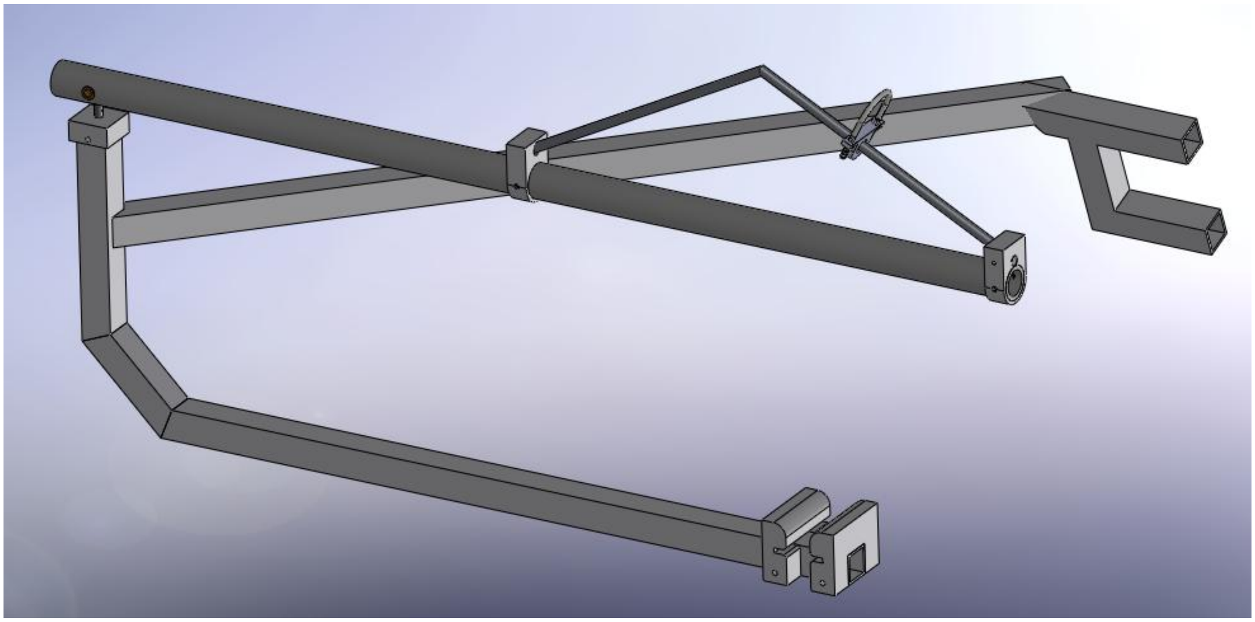


Fig 3.02 Design Concept

3.1 Design Decomposition and Restraints

The axiomatic design process was chosen because linear progression assures that the end product is dependent on a hierarchy of function requirements. The axiomatic design process is a methodology which uses matrices to identify the goal of the design into functional requirements and then design parameters. Functional requirements, the basic needs of the design, are identified and the design parameters are realized and added to the matrix to form a view of where the focus should be. Figure 3.1 shows the matrices used in our design process.

0	FR	Sweep Rigging
1	FR	handle support
1.1	FR	attach to erg
1.2	FR	handle connects to support
2	FR	attach handle to chain
2.1	FR	chain stays centered
3	FR	handle similar to aor
3.1	FR	handle moves up and down
3.2	FR	handle moves in arc

0	DP	Design
1	DP	structure
1.1	DP	front and back clamp
1.2	DP	handle connects to chain
2	DP	bearing assembly
2.1	DP	linear bearing on shaft
3	DP	PVC handle with pivot
3.1	DP	flanged bearings
3.2	DP	free swing eyebolt

Fig 3.1 Axiomatic Matrices

3.2 Function Requirements

FRI-Handle Support

In order for the design to work it must be attached to the ergometer. The design parameter taken from this function requirement was a skeletal structure with two arms that would connect to the ergometer using a simple clamping system. The original designs composed of six separate ideas which were streamlined into the top two competitors in final design. In the end two designs were merged into one creating a light weight, compact design using features from the remaining two designs.

FR 2-Attach Handle to Chain

Now that we know a structure is part of our function requirements we can move onto the chain connection. Concept 2 ergometers use air pressure and tension to create resistance when the rower moves through the rowing motion. The chain attachment must stay centered on the slide because of the Concept 2 design which has a guide/barrier preventing the chain from misaligning and coming off the sprocket. At the same time the chain attachment cannot hinder the full range of a rower, otherwise the proper technique cannot be attained.

FR 3-Handle similar to Oar

Once we have a chain attachment implemented, the handle can be designed with the specific function requirements of movement in the x and y plane. These two function requirement are dependent on FR 1 and FR 2. The handle will have a pivot point position dependant on the structure and a length dependent on the chain attachment.

3.3 Design Parameters

DP1 Structure

The structure is the most vital part of the design which is why, as a function requirements, it is placed first in the hierarchy. Without a structure none of the following function requirements can be easily mounted. As previously stated the structure is based on two separate designs. The first design utilizes the existing framelock mechanism between the two parts of the ergometer as a place to connect the structure. The second design had a back stay, connected to the ergometer's rear brace, and a front stay connected above the footrest similar to the rigging of a racing shell. In order for our design to work properly the two ideas were merged into one that uses the front stay above the footrest and a back stay centered below the seat, located fourteen inches behind the footrest. The ending design calls for clamps (figures 3.31, 3.32) on both stays to keep the structure in place without damaging the ergometer.

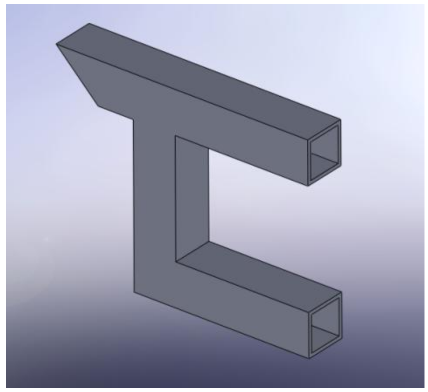


Fig 3.31 Front Clamp

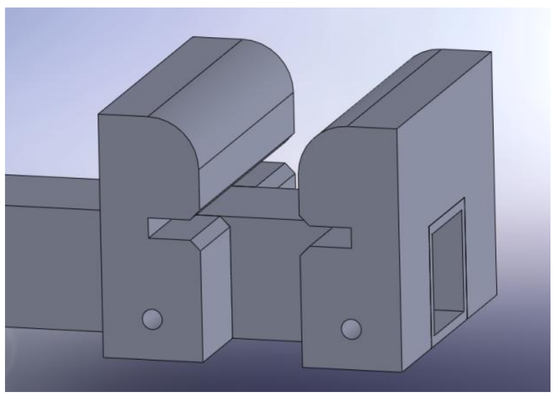


Fig 3.32 Back Clamp

The first prototype (figure 3.33) built was made from cost efficient PVC piping which allowed us to test for rower variations in size and build. This first prototype also allowed us to test the theoretical measurements and angles.

Fig 3.33 Prototype A

The second prototype is made from aluminum for strength, durability, machine ability, and weight. In order to deduce the viability of the chosen material the following calculations were done to prove that the aluminum can withstand the forces of regular use by rowers.

Maximum Shear force for a 1 ½" square aluminum rod with a thickness of $^1/_8$"

Material = Al 6061 T6

Information from ASM Materials Data Sheet

Tensile Strength = 40,000 psi

Shear Strength = 30,000 psi

Shear Strength @ Weld = 6,000 psi

$$A_s = L_O^2 - L_I^2$$

$$A_s = 1.5^2 - 1.25^2$$

$$A_s = 0.6875$$

$$F = 4125\ lb$$

On another note, for purposes of marketability the ergometer must be easily carried and attached by one person.

DP2 Bearing Assembly

To attach the chain to the sweep rigging a simple plastic bearing sleeve (figure 3.34) is used.

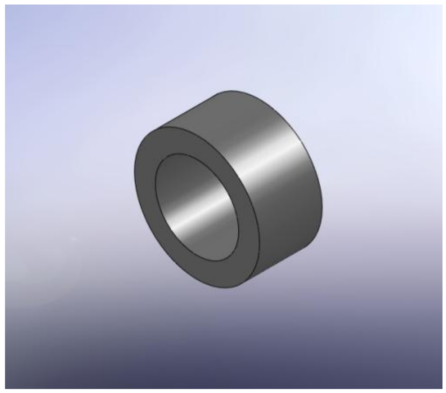


Fig 3.34 Plastic Bearing Sleeve

The delrin was calculated to have a conservative maximum compressive force of 785 lbs using the following calculations:

Delrin bearing: ID ½", OD ¾" and L of ½"

Information from McMaster-Carr

Max Pressure = 1000 psi

The area that the force is transmitted through the bearing is one half of circumference multiplied by the length

$$A = \pi r^2$$

$$A = \pi \left(\frac{1}{2}\right)^2$$

$$A = 0.785\ in^2$$

$$F = 785\ lb$$

The aluminum housing (figure 3.35) is nothing more than a convenient point of connection between the chain and the Delrin bearing without impeding the movement on the shaft. The coefficient of friction for the bearing is between 0.1 and 0.3. Once the bearing assembly is completed it is placed on a shaft which is supported by braces (figure 3.36) on either side.

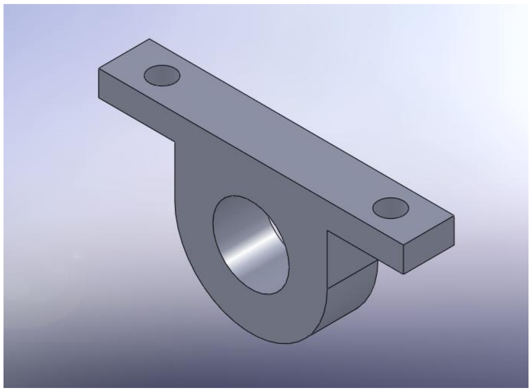


Fig 3.35 Bearing Block

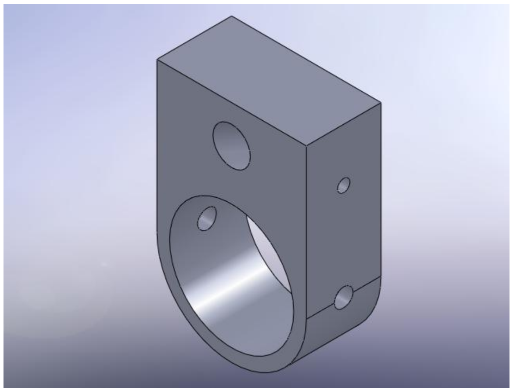


Fig 3.36 Brace

DP3 PVC Handle with Pivot

To connect the structure with the bearing assembly a handle (figure 3.37) becomes part of the matrices as a design parameter.

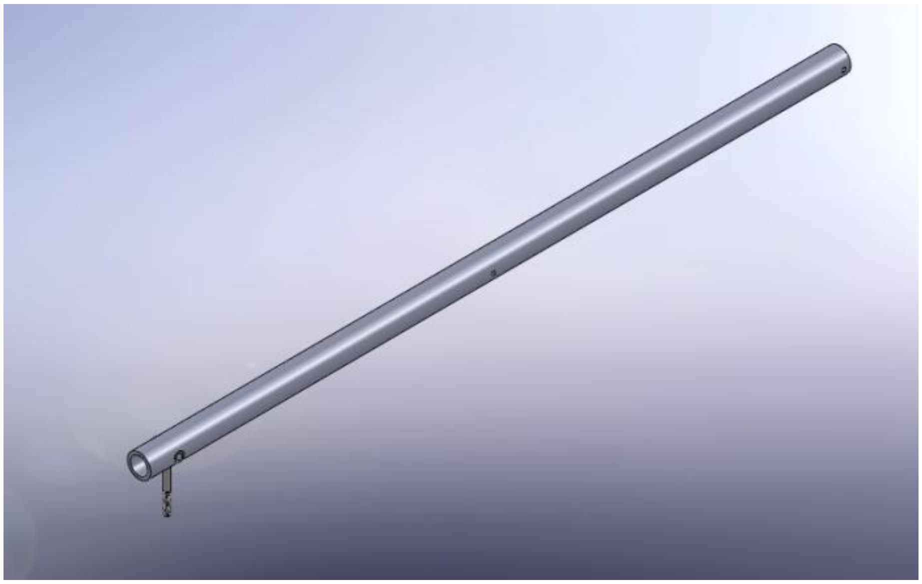
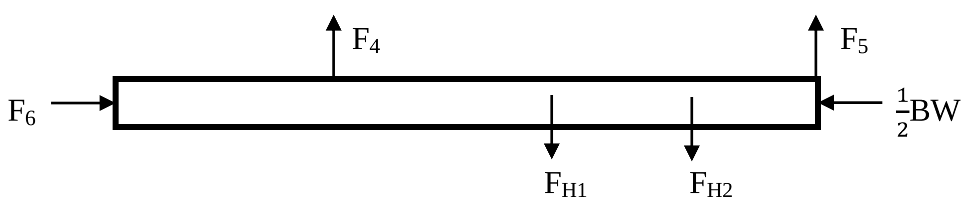


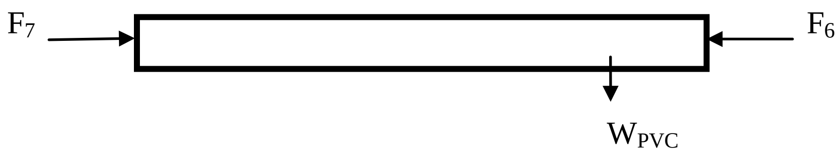
Fig 3.37 Handle with Pivot

The handle is vital to a rower in order to make the same movement off and on the water. To attain the proper motion the handle must pivot in two planes, have ample space for rowers to grip, and for braces to attach. The proper material for both the handle and brace are crucial to designing a handle that can withstand rowing forces.



$$F_4 + F_5 = F_{H1} + F_{H2}$$

$$F_6 = 125\ lb$$



$$F_7 = W_{PVC} + F_6$$

$$F_7 = 125.022\ lb\ @\ \theta = 1.08\ degrees$$

PVC Pipe with an outer diameter of 1.66 and an inner diameter of 1.255

Information from McMaster-Carr

Max Pressure = 520 psi

Force is transmitted to the PVC Pipe through the braces.

The braces are 1 in thick

The area that the force is transmitted through the pipe is one half of circumference multiplied by the thickness

$$A = \frac{\pi t d}{2}$$

$$\mathrm{A} = \frac{\pi(1.66)}{2}$$

$$\mathrm{A} = 2.61\ \mathrm{in}^2$$

$$\mathrm{F} = 1356\ \mathrm{lb}$$

The handle pivot connection was created using an eyebolt (figure 3.38) and bronze flange bearings (figure 3.39), allowing ease of movement in two planes. The proper length for a handle was taken from interviews with experienced rowing coaches whom defined the proper oar length, from pivot to end of handle, between 43 and 47 inches while leaving extra space for the inside hand [10]Braces are attached on either end of the grip tape to hold the shaft which the bearing assembly is riding.

Fig 3.38 Eyebolt

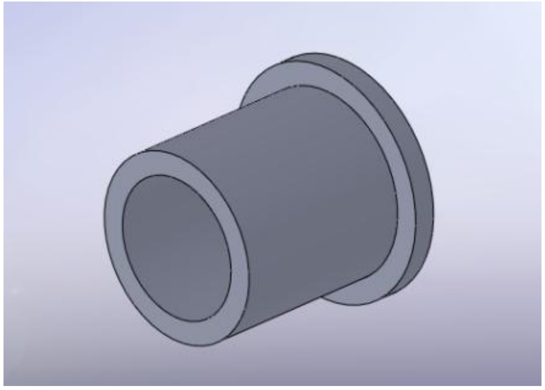
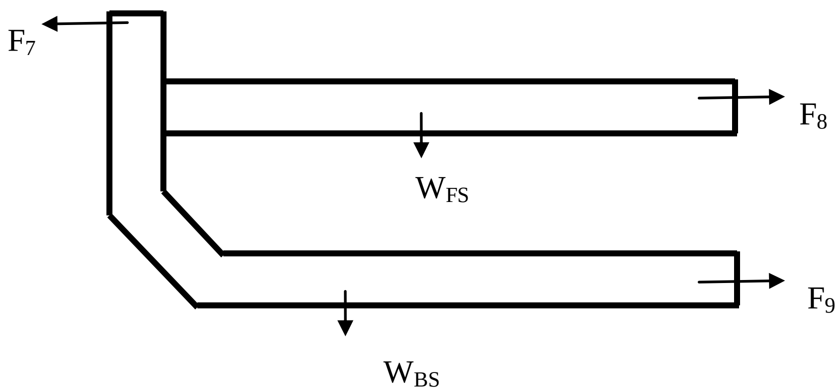


Fig 3.39 Flange Bearing

4. Description of Parts

4. 1 Structure

The purpose of the structure is to create a mount for the pivot of the handle which behaves similarly to a rigger on a racing shell. It is important that the structure is light yet strong enough to withstand forces emanating from the handle.



$$F_{BS} = 130\ lb$$

$$F_{FS} = 128\ lb$$

In order to make the structure compatible with the existing Concept 2 ergometer the structure had to be mountable, meaning the structure could not touch the ground because it would need to move with an ergometer while the ergometer is on slides (figure 4.11). The structure utilizes 45 degree and 90 degree angles which are vital to the design as braces for the complete structure (figure 4.12).

Fig 4.11 Concept 2 Ergometer on Slides

Fig 4.12 Structure – Prototype B

For our design to properly mount, it is connected on two points on the ergometer. The front stay attaches to the front of the ergometer, on the incline above the footrests and below the mounting holes for the handle holder (figure 4.13). This point is approximately 14 inches high perpendicular to the ground and 5 inches above the framelock along the front of the ergometer. This point was chosen for the following reasons; rowers need space above the footrests to make adjustments, our design cannot interfere with existing Concept 2 components, and this point needs to be low enough that rowers' hands would not be in any danger of making contact with the device.

Fig 4.13 Front Clamp Position– Prototype B

The second mounting point is on the underside of the slide approximately 14 inches behind the framelock (figure 4.14). The constraints of the front mounting point and the desire to implement 45 and 90 degree angles for stability forces the second mounting point to this position.

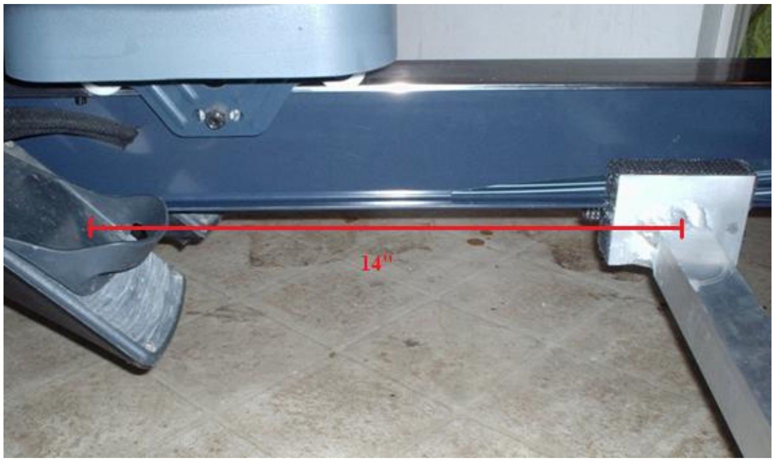


Fig 4.14 Back Clamp Position – Prototype B

Attaching our design to the Concept 2 ergometer is simple. The front clamp slides on between the footrests and the handle holder. The back of the structure slides under the slide, using the front clamp as a pivot. During the second step the top of the structure must be flush against the underside of the slide. The slot of the back clamp is then fitted onto the slide. The second piece of the back clamp is then positioned in the same way on the opposite side of the slide. The aforementioned steps are pictured below in figure 4.15.

Fig 4.15 Procedure – Attaching Structure

4.2 Clamps

In order to attach the structure to the ergometer two clamps are placed where the front and back stay make contact with the ergometer. The clamps are simple yet effective without damaging the ergometer.

The front stay clamp is placed on the front of the slide above the foot stretchers and below the mounting holes for the handle holder. To simplify the attachment process the front stay clamp is perpendicular to the front of the ergometer so that it sits at an angle in relation to the ground. The front stay clamp slides on easily allowing ample room for a rower to adjust their footrests and stays on with a quarter inch bolt through the top which screws into a threaded block at the bottom of the clamp (figure 4.21).

Fig 4.21 Front Clamp

The back stay clamp is a more complicated design because of the irregular I shaped beam that is the slide of a Concept 2 ergometer. To create the most contact with the ergometer the top half of the clamp is flush against the main body of the slide. The bottom of the slide has protrusions (figure 4.22), enabling the clamp to have a tight fit. This set of clamps are made with identical pieces placed on either side with the one piece welded to the structure (figure 4.23) leaving excess square tubing that extends out the other side of the slide. The second piece slides onto the exposed square tube and is secured with a quarter inch bolt that passes through the lower half of the clamp (figure 4.24).

Fig 4.22 Protrusion – Bottom of Slide

Fig 4.23 Back Clamp on Ergometer

Fig 4.25 Back Clamp

4.3 Handle

The handle of our design is attached to the structure at a pivot point similar to boat rigging. The handle is composed of thick walled PVC pipe that is comparable to the diameter of an oar with mounting holes for braces and pivot hardware.

Pivot hardware (figure 4.31) is attached to the farthest point from the grip, allowing ample length to create the perfect arc. In order for the handle to move in the right directions the pivot must allow for movement in the x and y plane. Using an eyebolt (figure 4.32) the handle is able to move forward and back around the pivot. To attain the proper lean, maximizing a rower's full length and strength, flange bearings (figure 4.33) are used to create a minimal friction area where a simple bolt is secured and made perpendicular to the eyebolt (figure 4.34).

Fig 4.31 Pivot Hardware

Fig 4.32 Pivot Assembly

Fig 4.33 Flange Bearing

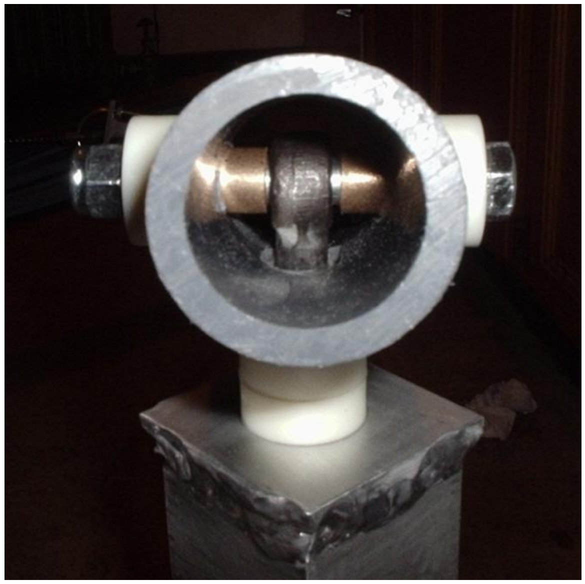


Fig 4.34 Pivot Assembly

Grip tape is applied around the pipe between the two braces so the rowers have a non-slip surface (figure 4.35). The grip tape must be tightly wound around the pipe and unlike oar grips the handle grip does not need to be water proof.

Fig 4.35 Attached Handle

4.4 Braces

Braces play a vital role in our design because they hold the shaft in place as the rower moves back and forth. For simplicity of design the two braces are identical pieces (figure 4.41). The first hole is larger which tightly fits around the handle so that no hardware is necessary to stay in place. The braces are placed twenty-nine inches apart (figure 4.42) allowing different sized rowers the ability to hold on to the handle at a comfortable place.

$$F_3 = F_5$$

$$F_2 = F_4$$

$$F_5 = 250\ lb$$

$$F_4 = 125\ lb$$

Fig 4.41 Attached Brace

Fig 4.42 Brace/Shaft Assembly

The second smaller hole is only one ½ inch in diameter and made at an angle to easily accommodate the shaft (figure 4.43). The shafts are held in place with set screws. The angle of the hole is determined by the shaft and has a tight fit to ensure the minimal amount of slippage when in use.

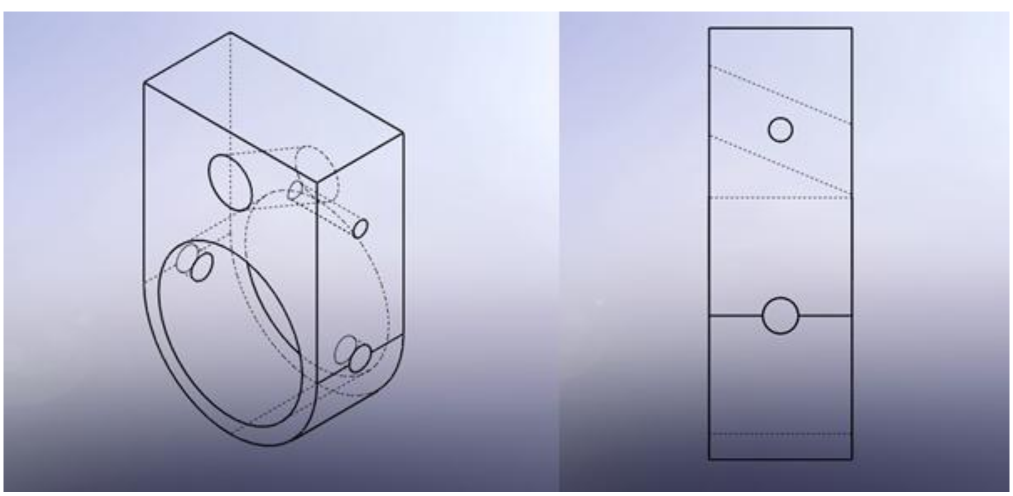


Fig 4.43 Line Drawing - Brace

4.5 Shaft/Bearing

In order for the design to work and for the chain to stay centered along the slide calculations had to be done to determine the offset angle. The following is the mathematical calculations and resulting approximations taken from the calculations. The following is the calculation of the curve necessary for the bearing to stay centered above the slide, throughout the rowing motion:

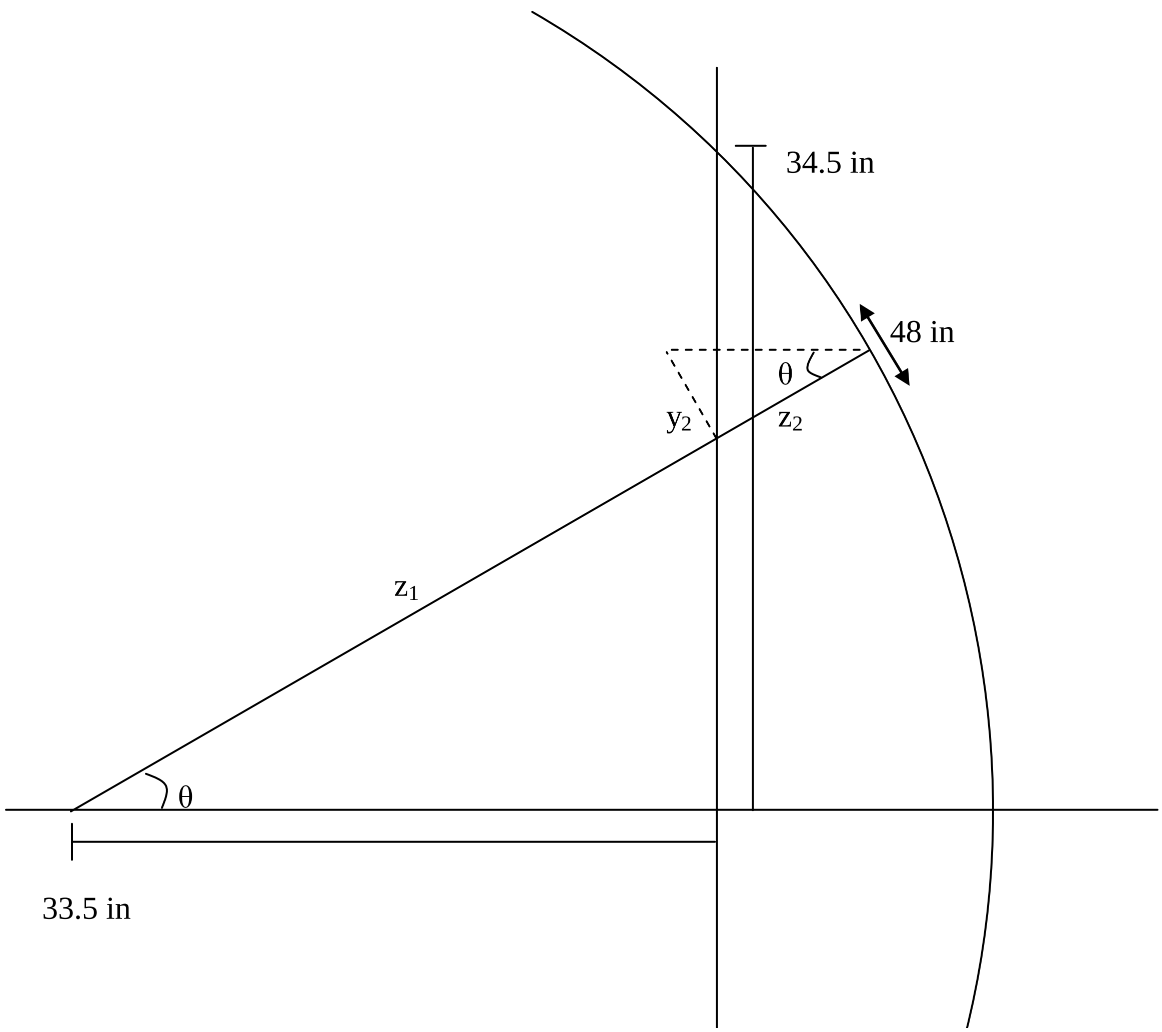


Fig 4.51 Shaft Curve - Sketch

$$z_2 = 48 - z_1$$

$$\cos\theta = \frac{33.5}{z_1}$$

$$\theta = \cos^{-1}\left(\frac{33.5}{z_1}\right)$$

$$y_2 = z_2 \tan\theta$$

$$y_2 = (48 - z_1)\tan[\cos^{-1}\left(\frac{33.5}{z_1}\right)]$$

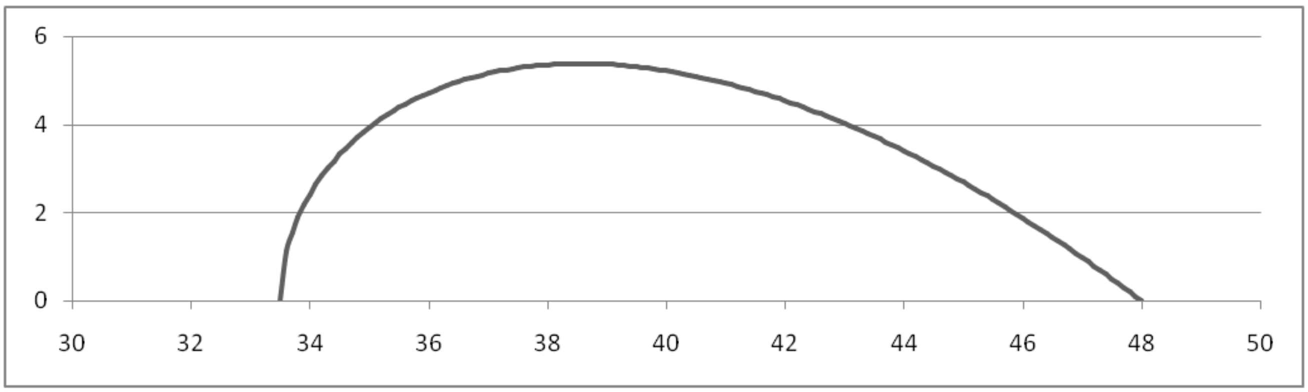


Fig 4.52 Shaft Curve – Graph Calculation

It was decided to approximate the slope near the outer handle (near 48 inches) with a straight line that has a slope of 6/14.5.

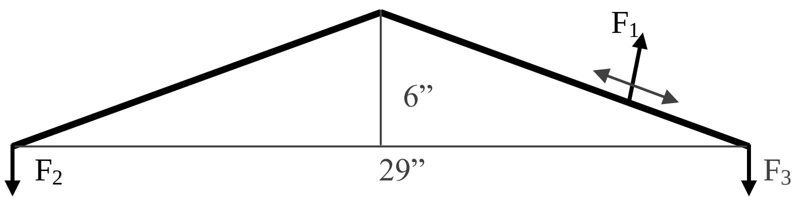
The angle produced allows the slow progression of the bearing across the shaft, from the outside hand to the inside hand (figure 4.53).

Fig 4.53 Attached Bearing Assembly

The delrin bearing is press fit into a bearing block (figure 4.54) which connects to the replaced U bolt hardware (figure 4.55) of the ergometer. Delrin is strong enough to withstand the forces applied by the rower and the chain. The following calculations show the amount of force on the delrin (F_1) bearing plus the aluminum bearing block, the diagram also shows where forces will be applied which does not vary from one rower to another.

Forces on Rod

(numbers given are for max value)



$$F_1 = body\ weight$$

$$F_1 = highest\ body\ weight$$

$$F_1 = 250\ lb$$

$$F_3 = 250\ lb$$

$$F_2 = 125\ lb$$

Fig 4.54 Bearing Block on Shaft

Fig 4.55 Chain Attachment

4.6 Hardware

Racing shells use one of two size bolts, the 10mm or the 7/16” which is the reason all the nuts and bolts on our design use a 7/16 wrench. A rower, coxswain, or coach will always have both available. This knowledge was implemented as part of our design to increase marketability.

The other piece of hardware is two set screws for the shaft. The set screws have tapered ends to easily catch the shaft material, making it more difficult to come undone.

The handle pivot includes hardware that allows two different degrees of freedom. The flanged bearings on the outside of the handle are bearings that allow the rim to sit on the outside of the handle. An eyebolt rests between the flange bearings and a bolt fits through all three pieces of hardware. The eyebolt then secures with a nylon lock nut with nylon spacers for stability.

5. Testing and Analysis

5.1 Prototype Assembly

The prototype was assembled and placed onto a Concept 2 ergometer. The prototype is assembled in three parts, structure, handle, and pivot. Figure 5.11 is a closer view of the structure with welding joints highlighted, while figure 5.12 is a closer view of the back post welds. The structure is composed of eight parts welded together to create one solid structure that is both light and compact.

Fig 5.11 Structure Welds

Fig 5.12 Structure Welds – Back Post

Figure 5.13 shows the handle assembly with shaft angles highlighted to emphasize the simplicity of design.

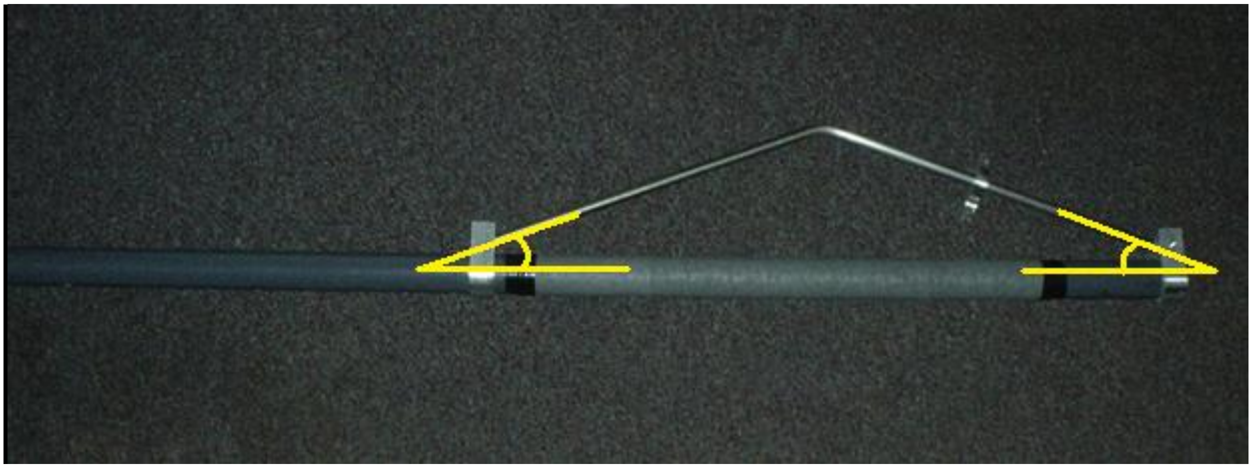


Fig 5.13 Shaft Angles

Figure 5.1d is an exploded view of the pivot assembly. The close up view shows the number of components used to achieve the correct pivot, forming the proper rowing technique. Nylon spacers are used to create stability without compromising the maneuverability of the rower.

Fig 5.14 Exploded View – Pivot Assembly

The following CAD drawing (figure 5.15) is the completed design with all components. Exploded views and previous drawings are more difficult to see, although the following does show the completer design.

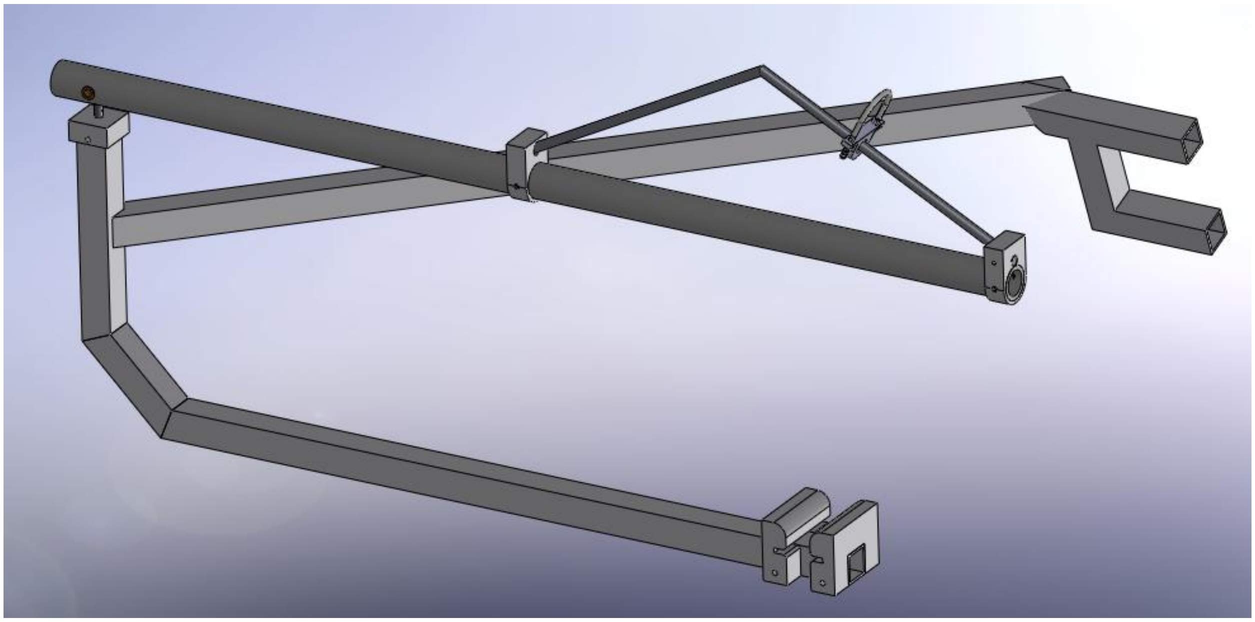


Fig 5.15 Complete Design Assembly

5.2 Rowing with the Sweep Rigging Attachment

Tests done with the Concept 2 ergometer were conducted by five female rowers. The five volunteers are all rowers from the Worcester Polytechnic Institute Varsity Crew Team with rowing experience ranging from two to eight seasons.

All rowers experienced a significant difference in their ergometer technique. Rowers were allowed to pull 100 meters with and without the sweep rigger attachment in a span of five days to find any difference between rowing on the original ergometer and rowing with the attachment. The average splits (the amount of time, in minutes, to row 500 meters) were recorded with all rowers pulling 26 strokes per minute. The differences in average spits for each rower are presented in the following graphs (figures 5.21-5.25).

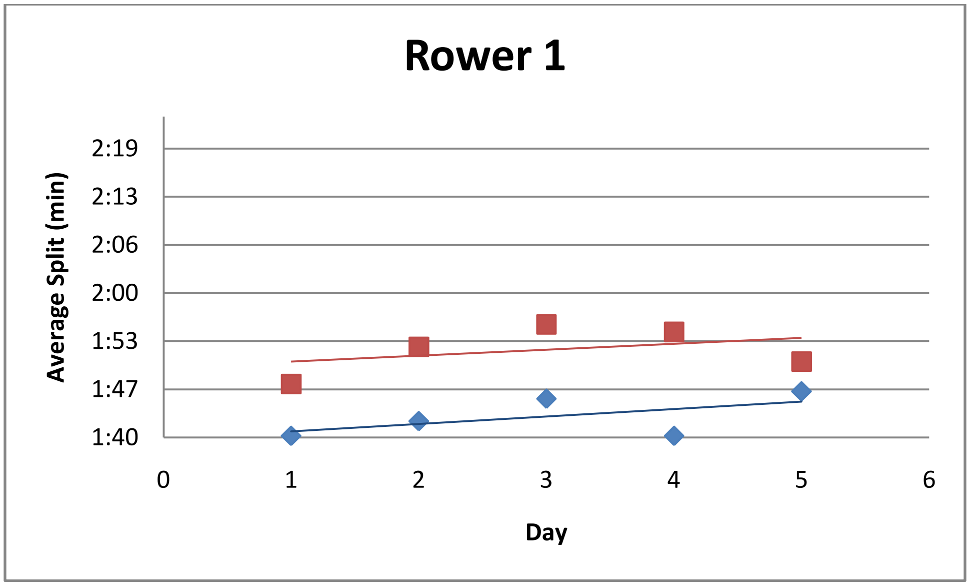


Fig 5.21 Rower 1 Average Splits

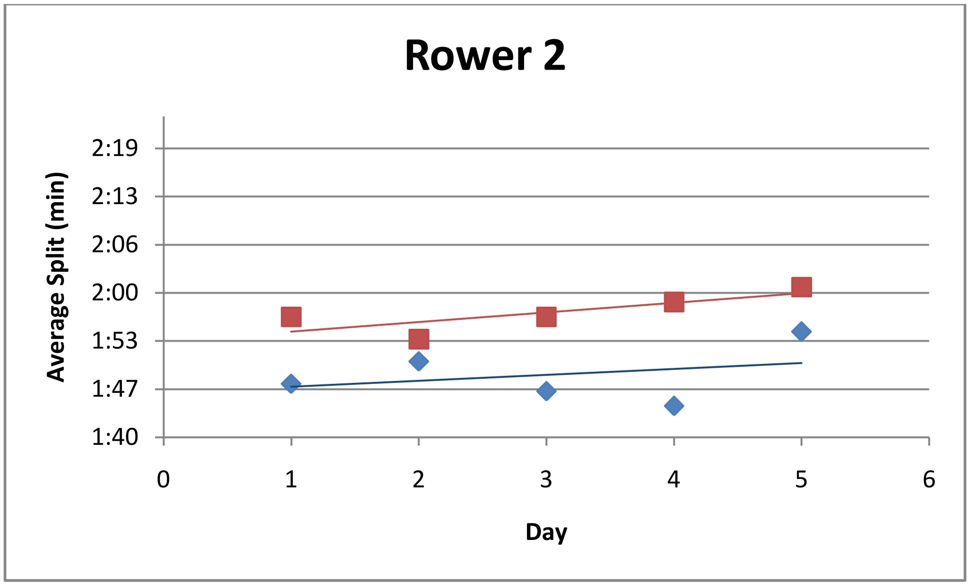


Fig 5.22 Rower 2 Average Splits

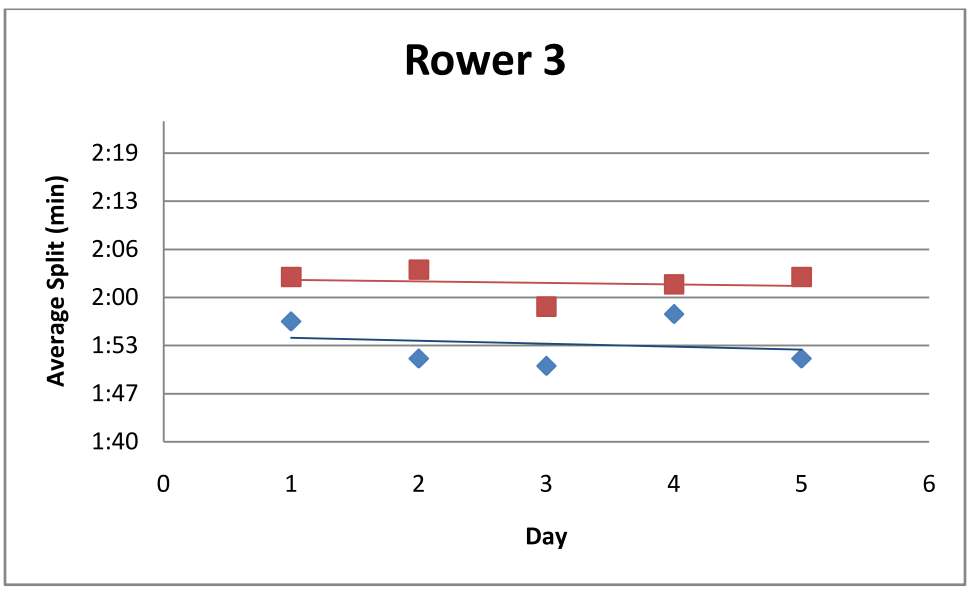


Fig 5.23 Rower 3 Average Splits

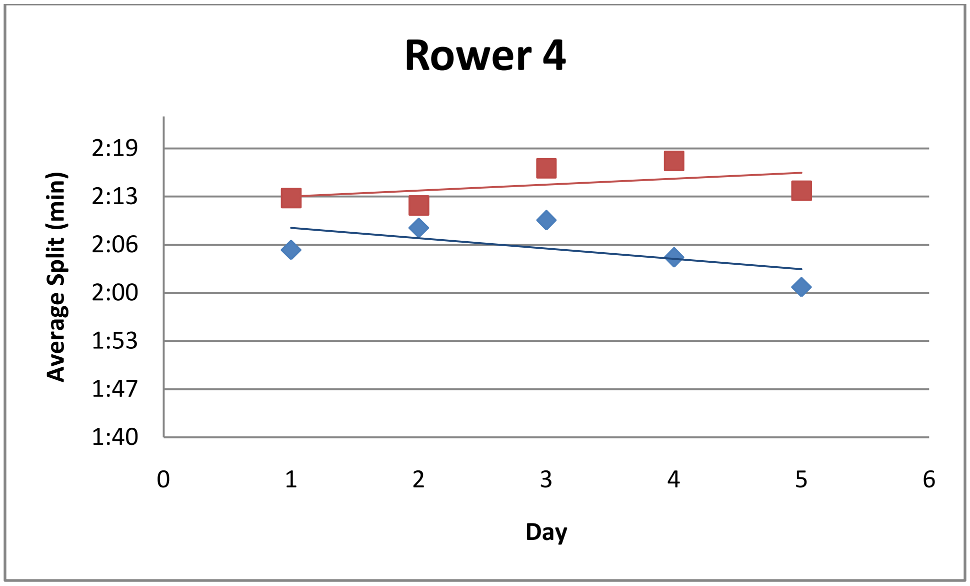


Fig 5.24 Rower 4 Average Splits

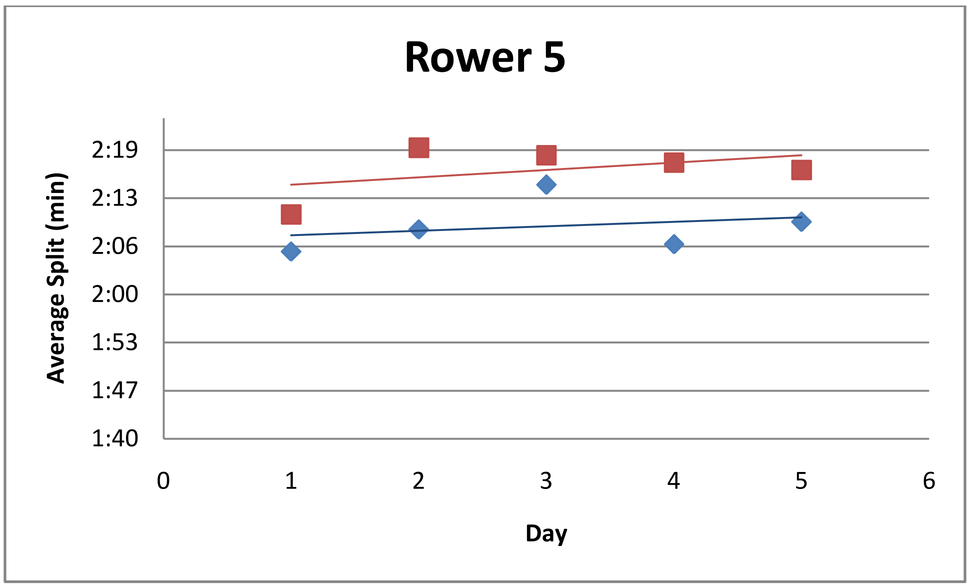


Fig 5.25 Rower 5 Average Splits

Every graph shows a comparison between rowing with and without the sweep rigger. Blue diamonds denote average splits without the sweep rigger and red squares denote average splits with the sweep rigger. Both sets of data have a resulting trend line which can be compared to each other.

The results show that rowing with the sweep rigger attachment adds an average of 8.36 seconds to average splits.

5.3 Rowing Experience

Along with tests for average splits a larger group of rowers were allowed to test our sweep attachment design. A total of 42 rowers took surveys and pulled a few strokes on an ergometer with the sweep attachment. The first set of questions was distributed before using the sweep attachment. The second set of questions was distributed after using the sweep attachment. Both sets of questions are accompanied by the results of the surveys.

Rowing: Ergometer vs. Sweep

1. What forms of exercise do you use during the season? (select all that apply)
    - **(42)** Ergometer
    - **(37)** Weight lifting
    - **(42)** Water practice
2. What forms of exercise do you use during the off season? (select all that apply)
    - **(42)** Ergometer
    - **(35)** Weight lifting
    - **(7)** Water practice
3. Do you use slides while using the ergometer?
    - **(28)** Yes
    - **(14)** No
4. How often do you use an ergometer a week, during the off season?
    - **(3)** 1
    - **(1)** 2
    - **(7)** 3
    - **(31)** 4+
5. How often do you get on the water a week, during the season?

- **(0)** 3
- **(8)** 4
- **(11)** 5
- **(23)** 6+

It can be easily seen from the first question of the first survey that during the season, both athletes and coaches heavily rely on practice on the water and on the ergometer and in many cases supplement training with weight lifting. There is a distinct shift in types of practice during the off season with most practices occurring without the coach and on the ergometer. Since part of perfecting a rower's technique is synchronizing with a fellow rower most rowers surveyed said that slides are used during off season practice. This was taken into account when the design excluded an extra leg for support. Although there is a decrease of number of practices a week from in season to off season there are still a great number of rowers who use ergometers at least four times a week, making our design all the more important.

After each person answered the survey they were allowed to attach the sweep attachment to an ergometer and pull a few strokes at a time (none lasting more than 30 seconds) at various pressures then asked to answer the following questions in reference to their experience.

The data gathered showed overall positive feedback. In most cases rowers needed help attaching the sweep attachment to the ergometer, although after the first time many rowers felt comfortable with the attaching process. From the first prototype the correct hand position was tested and all but the largest male rowers were able to find a comfortable position for their hands. Taller rowers, above 6 feet 6 inches found it difficult to reach their full length without brushing the chain guard with the handle. Others found the change from ergometer to sweep rowing hard to adjust resulting with few rowers putting the correct pressure on the pivot. Rowers who did put the correct pressure on the pivot were also those that got the most length throughout their drive.

During the release only the tallest of the rowers were unable to find a comfortable height for their hands at the release.

Rowing with Sweep Attachment

1. I was able to easily attach the sweep attachment?
   - ☐ **(2)** Strongly Disagree
   - ☐ **(13)** Disagree
   - ☐ **(21)** Agree
   - ☐ **(6)** Strongly Agree
2. I was able to find a comfortable position for my hands?
   - ☐ **(0)** Strongly Disagree
   - ☐ **(3)** Disagree
   - ☐ **(2)** Agree
   - ☐ **(37)** Strongly Agree
3. I was able to reach my full length?
   - ☐ **(1)** Strongly Disagree
   - ☐ **(9)** Disagree
   - ☐ **(7)** Agree
   - ☐ **(25)** Strongly Agree
4. I was able to put pressure on the pivot?
   - ☐ **(9)** Strongly Disagree
   - ☐ **(17)** Disagree
   - ☐ **(14)** Agree
   - ☐ **(2)** Strongly Agree
5. I was able to find a comfortable position for the handle during the release?
   - ☐ **(4)** Strongly Disagree
   - ☐ **(12)** Disagree
   - ☐ **(15)** Agree
   - ☐ **(11)** Strongly Agree

6. Iteration

Initially the structure and attachment of the sweep rigger was the focal point of our design. Our process put heavy emphasis on the structure and mode of attachment because of the need for stability at the pivot. The first designs were free standing as stability was our main concern but the switch to tubing for our main structural framework and the addition of a 45 degree angle to better support the pivot removed the need for the extra support. The choice of 6061 aluminum (for tubing and braces) was made because it offered good machinability, high tensile and compressive stress properties, and was cost effective. It was easy enough to machine clamps with tight fits, which created excellent stability.

During the design process the linear bearing was changed after the PVC prototype was tested. The design originally used a linear bearing on a straight rod which was mounted parallel to the handle. This design failed since position of the bearing on the shaft was not consistently centered over the slide. Then the design was modified so the shaft was at an angle to the handle, which allows the bearing to move easily to a position centered over the slide throughout the sweep motion.

The decision to change to a custom bearing was made when the linear bearing was found to have difficulties moving along the new shaft. Our design uses a delrin plastic bearing in an aluminum bearing block which attaches to a u bolt; however this design still has some drawbacks. The lack of lubrication and the sharp edges of the delrin bearing create friction that slows the motion of the bearing along the shaft, forcing the chain to catch the edges of the chain gate on the ergometer. This movement causes unnecessary friction and thus reduces the power output of the rower.

Although there were drawbacks to the custom bearing, the results of tests showed that the concept worked correctly with some flaws to the average split when rowing. To reduce the friction that resulted from the custom bearing a new bearing would have to be designed. The major flaw of the existing custom bearing is the sharp edges and lack of lubrication. The new design would utilize two brass pulleys on opposite sides of the shaft. Each pulley has grooves for the shaft to slide along and bearings for the bore. As shown in figure 6.0, connecting the two pulleys together then attaching to the existing chain would be another concept that would need more development.

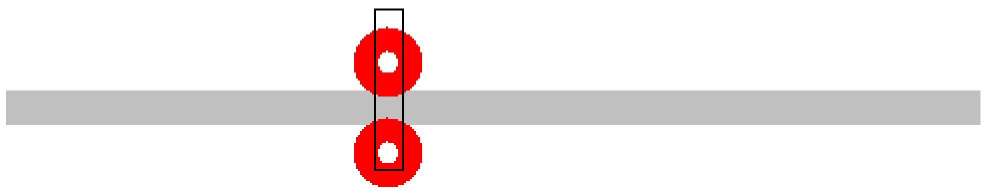


Fig 6.0 Iteration – Bearing Assembly

7. Discussion

The prototype of the ergometer rigger was successfully designed, built, and tested. The design satisfies all major objectives. The rigger is easy to attached and detach to the ergometer. The only tool needed is a 7/16” wrench, a common rowing tool. Rowers are able to sweep row on an ergometer using the correct technique. The rower is able to take advantage of slides while using the rigger which completely simulates rowing on the water.

Testing with rowers revealed that our sweep rowing design recorded higher splits for the same power input (figures 5.21-5.25). The difference in reported power was small and is attributable to excessive friction in the bearing over the shaft.

However, the main objective of our design was achieved as the rowers reported a significant change in the feel of rowing on the ergometer. All rowers reported that their muscles were properly engaged in the sweep rowing fashion. During testing it became obvious that the correct muscle groups, in relation to the lean, were being used. The outside muscle groups would flex during the catch, which is the result of proper technique.

There were minor flaws with our custom bearing which resulted in excessive friction between shaft and bearing. These flaws would need to be addressed in any future model of the ergometer rigger.

8. Conclusion

I. Based on the testing and analysis, the project team concludes that the major goals and objectives have been achieved as set at the beginning of the project.

II. Average splits show an overall increase which can be resolved if the proposed changes to the custom bearing were implemented.

III. This design replicates on the water rowing on the ergometer.

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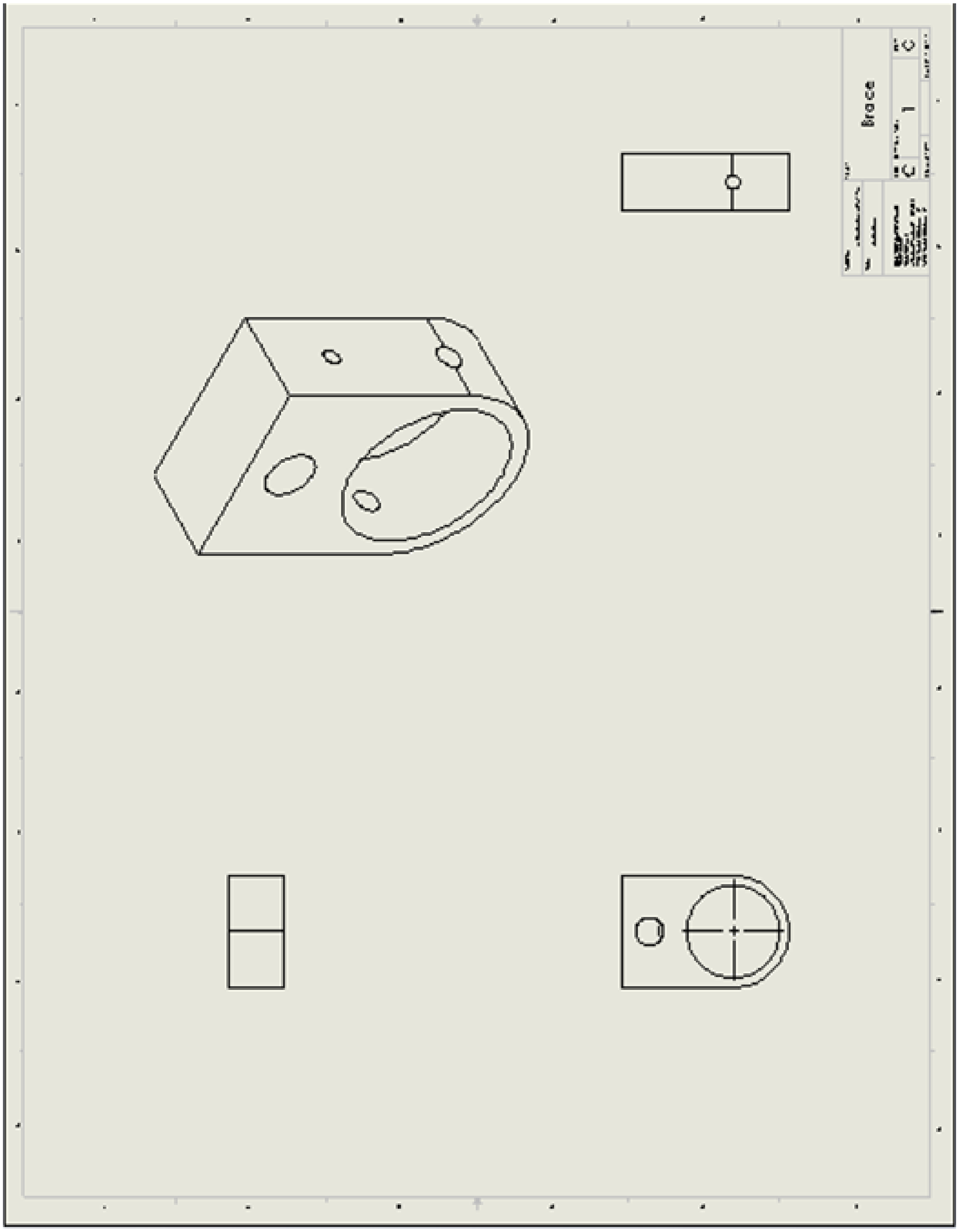
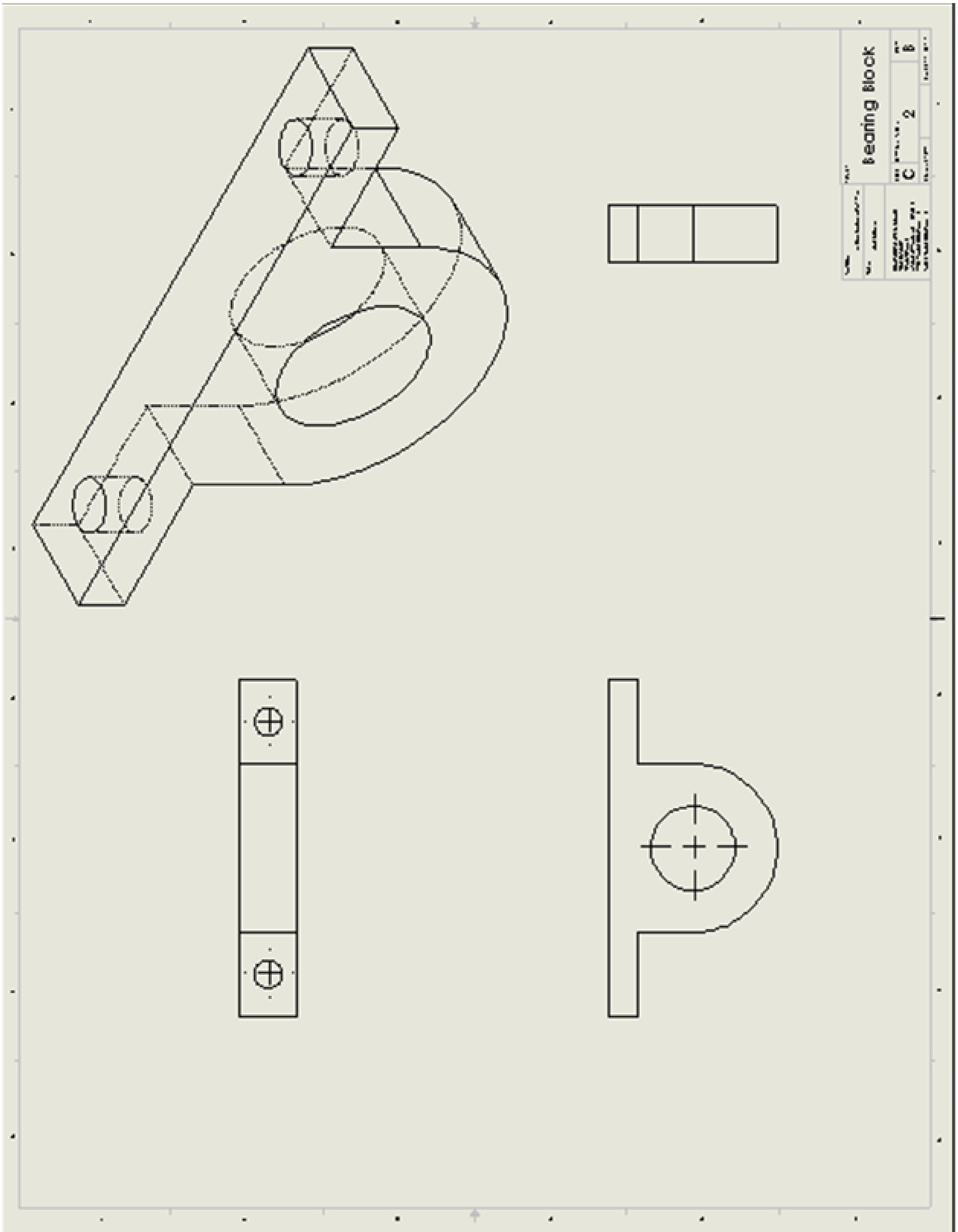
Appendix A

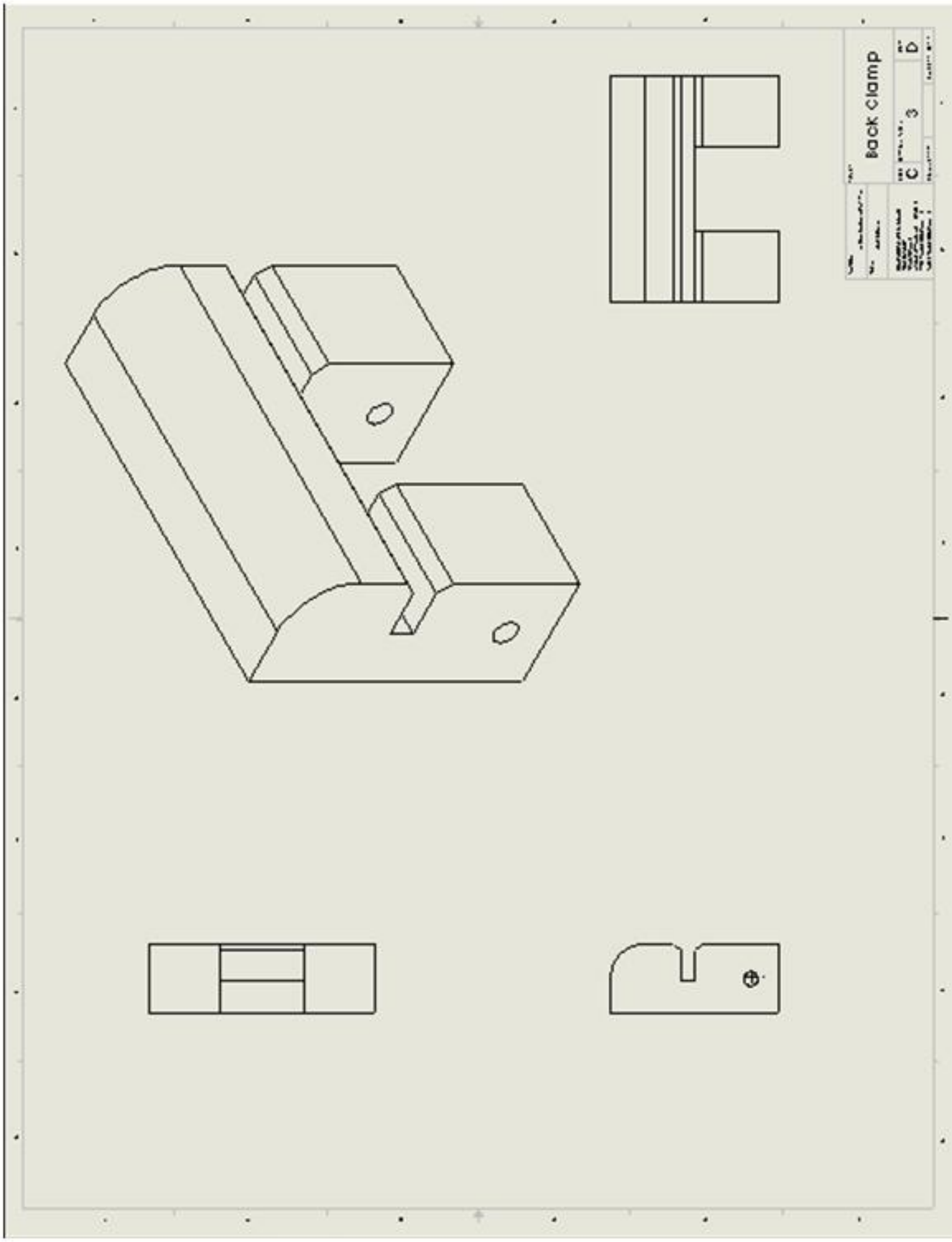
Drawing 1 – Brace



Drawing 2 – Bearing Block



Drawing 3 – Back Brace



Drawing 4 – Pivot Cap